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GEOPHYSICS.—*Thermal gradient of Kilauea Lava Lake.* T. A. JAGGAR, JR., Hawaiian Volcano Observatory.

Experimental temperature measurement with Seger cones in steel pipes thrust into the lava and flaming cones in 1917, when the lava pool of Halemaumau became accessible, yielded results of increasing accuracy as the method was improved and the sources of error or failure were discovered and eliminated.

The temperature of the fountains and grottoes, where gas effervescence induces ebullient doming, flaming, and spraying of incandescent melt, is now well known.[1] Excessive oxidation of the combustible constituents S, CO, and H on contact with air makes the confined and continuously flaring grottoes hotter than the central fountains. The temperatures vary, but 1130°C. for the fountains and 1180° for the open grottoes (fig. 1, circles) are recorded measurements approaching the maximum. Measurements in the past have been made with Féry[2] and Holborn-Kurlbaum optical pyrometers and with the platinum-rhodium element, and have shown that the surface temperatures of the Kilauea magma range from 940° to 1185°. Temperature measurement below the surface, or in the gas-filled chambers and orifices of flaming blowing-cones on the benches, has not been attempted before this year.

[1] Report Hawn. Volcano Observatory, Boston, January–March, 1912, p. 51. Bul. Geol. Soc. Amer., **24**: 601. 1913. Am. Journ. Sci., **36**: 151. 1913.

[2] Proc. Am. Acad. Arts and Sci., **47**: No. 3. 1911.

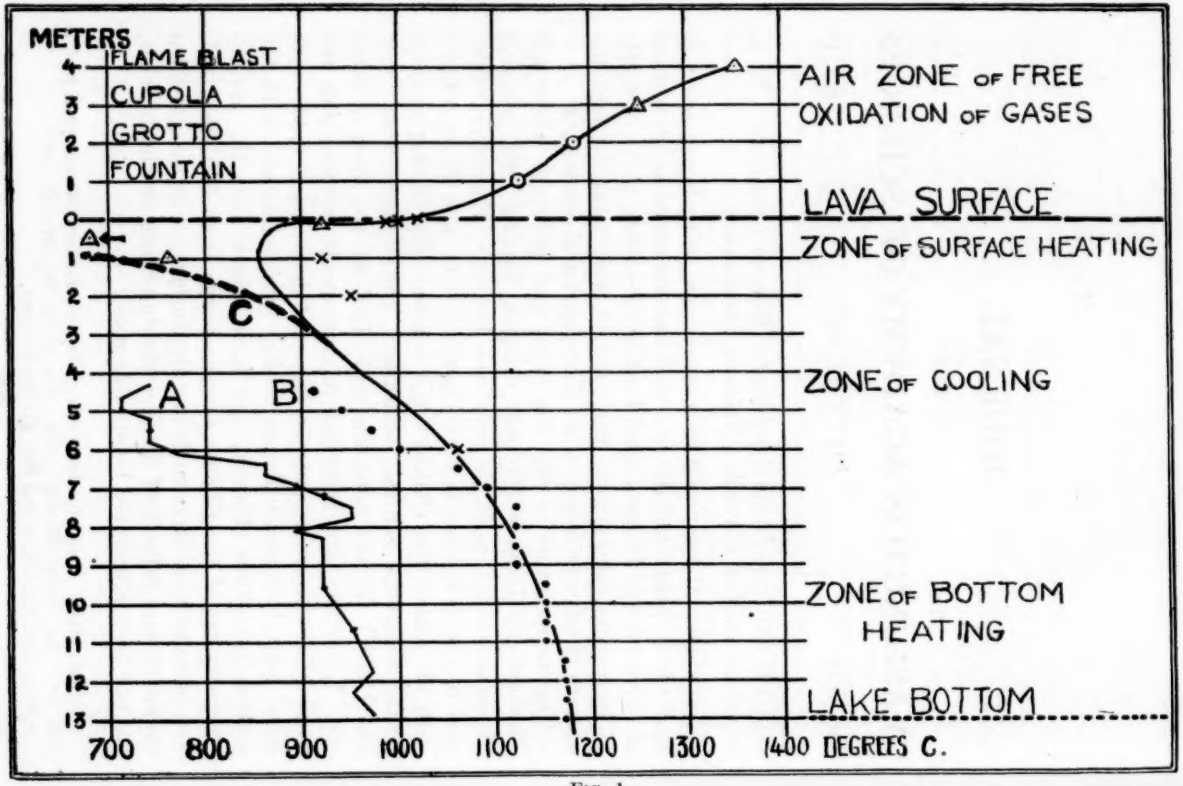
METERS
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
FLAME BLAST
CUPOLA
GROTTO
FOUNTAIN
AIR ZONE OF FREE OXIDATION OF GASES
LAVA SURFACE
ZONE OF SURFACE HEATING
ZONE OF COOLING
ZONE OF BOTTOM HEATING
LAKE BOTTOM
A
B
C
700
800
900
1000
1100
1200
1300
1400 DEGREES C.

FIG. 1

The writer determined by sounding on January 23, 1917, that the liquid lava in the lake was 14 meters deep, and that it rested on a seemingly pasty resistant bottom. This bottom was partially uncovered and revealed by subsidence of the liquid part of the lava column in February, 1917, confirming the soundings. Soundings of the remnant liquid pool on March 24 showed that the depth had diminished to 9 meters. After rising had been resumed, on May 2, the depth at the same locality was 13 meters. The liquid of the lake magma rises through conduit wells in the bench magma and circulates by convection through the conduits and sinkholes, the semi-solid bench magma forming the lake bottom and margins.

The thermal gradient of the liquid lake to its bottom is not the gradient of the lava column. That could only be determined by profound soundings along with temperature measurements in the conduits and sinkholes. The liquid lake is a shallow pool of lava continually engulfing vesicular crusts, which must be full of air, and which do not melt at once, as the upper temperatures are not those of superfusion. The determination of the gradient of the pool is of interest to show (1) whether reaction between gases rising from the bottom produces increased heat upward, or (2) whether surface radiation and expansion of the gases in vesicles make a graded cooling effect upward, or (3) whether a combination of these two processes, and also surface oxidation of the gases, bottom oxidation due to foundered crusts containing air, or bottom radiation, in some way complicate the curve. That it is a smooth curve seems unquestionable. Condition (3) seems nearest the measured gradient.

The measurements of 1917 are divided into three groups: group 1 (indicated by triangles in the accompanying diagram), January-March reconnaissance of method and surface temperatures; group 2 (indicated by crosses) in which the upper gradient was accurately determined in April with small steel pipes as containers of Seger cones; and group 3 (dots, *A* and *B*), lower gradient determined May 2 with special apparatus, the corrected error being due to air cushion in large pipe. It was found in the earlier experiments that pipes from 3 to 8 cm. in-

ternal diameter, containing Seger cones with their tips held free in air, failed to transmit the full temperature of the melt to the cones, owing probably to circulation of the air and consequent heat insulation for the limited time of exposure (five to eleven minutes). In later tests with 12-mm. pipes the results were accordant with tests in glowing caverns where the Seger cones are exposed directly, and with the observed incandescence. Accordingly where a large pipe is used to contain a removable series of batteries of cones exposed all at once, the relative temperatures are measured, but the figures are too low by an error approximately constant. *A* and *B* of the diagram show respec-

TABLE 1

GROUP 1. UPPER TEMPERATURE (TRIANGLES)

DATE	LOCATION	EXPOSURE	TEMPERATURE (SEGER CONE EFFECT)	CONDITIONS
1917		*min.*		
January 11	1 meter below surface of lake	6	Fusibility 990° unaffected	Special steel container for 6 Seger cones in steel cylinder 7.6 cm. internal diameter attached to steel pipe 2.5 cm. internal diameter. Pipe bent sharply at lava surface, straight above *and below*
January 15	1 meter below surface	11	Fusibility 770° unaffected	Cylinder 7.6 cm. Compare April 5
January 18	20 cm. below surface	1	Fusibility 870° slightly affected	Steel pipe 2.5 cm. internal diameter, heated first in air 30 cm. above lake 30 minutes. Seger cones in spiral of spring steel in sealed end of pipe. Trouble with moving crusts
January 18	50 cm. below surface	3	Fusibility 590° unaffected	2.5-cm. pipe, heated first in air 27 minutes, much crust trouble
January 18	10 cm. below surface	3	Fusibility 1070° unaffected	2.5-cm. pipe, heated first in air 27 minutes, much crust trouble
January 22	1.5 meters below surface	5	1070° fused	2.5-cm. pipe, heated first in air over fountaining grotto 10 minutes, then submerged in boiling grotto-lava

TABLE 1—Continued

DATE	LOCATION	EXPOSURE	TEMPERATURE (SEGER CONE EFFECT)	CONDITIONS
1917		*min.*		
January 26	3.6 meters above lava in blowing cone	9	1130° fused 1250° estimated interior cone 1350° estimated flame	2.5-cm. pipe, inserted in orifice 25 cm. diameter for a length of 70 cm. Blast flame emerging from orifice, pipe bathed in burning gas within. Pipe fuses and oxidizes to dripping incandescent product, eaten through for length of 23 cm. at flaming window. Color of pipe bright orange inside cone, yellow opposite flame. Temperatures estimated from relative glows and effects on steels. (Pipe, cap, spring steel container for Seger cones)
March 28	8 cm. within crevice 5 cm. across. Bench magma	5	920° fused	Calibration test in glowing orifice of cone, cherry-red chamber. Seger cones inserted successively one at a time on open wire. Basis for weighting other tests according to glow

tively the actual and the corrected readings of the lower gradient obtained in this manner, with the correction checked by measurements of group 2, in which small pipes were used inserted to a depth of 6 meters.

The upper lake gradient (crosses) of April 5–6 shows three points on a nearly straight line for 1, 2, and 6 meters of depth with 30°C. increment of temperature per meter downward. The average increment per meter of the lower, May 2, gradient (dots) is the same, a line joining the 5-meter point and the 13-meter point lying parallel to the April 5–6 line. The divergence of the two above the 6-meter point may be due to instrumental errors or may be due to a difference in convectional circulation on the two days. On April 5–6 the southeast pool where the experiments were made was streaming rapidly eastward on the

surface and making only thin skins; on May 2 this pool was partially separated from the larger lake and tended to form thick stagnant crusts. This surface was therefore much cooler on May 2, in accordance with the tendency of the *B* curve. A

TABLE 2

GROUP 2. UPPER LAKE GRADIENT (CROSSES)

DATE	LOCATION	EXPOSURE	TEMPERATURE (SEGER CONE EFFECT)	CONDITIONS
1917		*min.*		
March 30	15 to 20 cm. below surface	5	1020° fused	12-mm. pipe in streaming liquid lava of "bright lines" at margin of torn crust. Cones loose in sealed end of pipe. Accurate
April 5	1 meter below surface	5	920° fused	12-mm. pipe, thin crust, good conditions. Battery of Seger cones in iron wire gauze in sealed end of pipe. Accurate
April 5	6 meters below surface	5	1050° fused	12-mm. pipe, thin crust, good conditions. Gauze container. Accurate
April 6	2 meters below surface	5	950° fused	12-mm. pipe, gauze container, through thin crust, 1 meter from bright line of moving channel lava. Accurate
April 6	8 to 13 cm. below surface	5	990° unfused	12-mm. pipe, gauze container, through crust adjacent to bright line of moving lava. Lava tended to solidify around pipe
April 6	10 cm. below surface	4	990° fused	12-mm. pipe, gauze container, under crust 2 to 3 cm. thick, hence actual immersion in liquid 7 to 8 cm., next to bright line of moving lava, different locality from previous test same day

solid-line curve has been drawn in the diagram intermediate between the two, and this line is not far from a correct expression of the temperature of the Kilauea pool at its eastern margins,

on the side of the sinkholes, and relatively remote from the conduit wells. The conduit gradient, to the writer's thinking, should be different.

As indicated in the figure, four heat zones are present, from the hottest flame blast of burning gas in a high "blowing-cone" on the border benches, downward to the lava lake bottom.

The upper atmospheric zone shows a steep gradient of increasing temperature from 1000°C. at the "bright lines" of

TABLE 3

GROUP 3. LOWER LAKE GRADIENT (DOTS)

DATE	LOCATION	EXPOSURE	TEMPERATURE (SEGER CONE EFFECT)	CONDITIONS
1917		min.		
May 2	4.38 meters to 12.93 meters below surface	8	20 temperatures in series; 740° above to 970° below fused (*A* in figure 1, corrected in *B*)	Steel pipe 3.8 cm. internal diameter, 22.70 meters long, 20 gauze containers on wire in pipe all exposed at once. Immersed at angle 35°, vertical depths shown in *A*. 29 Seger fragments in each container, fusibilities 590° to 1290°. Corrected for probable constant error due to air insulation of large pipe and averaged for each half-meter, as smooth curve, at *B* (dots). Correction based on April 5–6 curve (crosses). Immersion to lake bottom, heavy crust on surface

the lava surface through the fountains, the confined grottoes on the lake shore, and still more confined cupolas of driblet cones, to the puffing vents where banners of flame play above these cones as natural blow-pipes of burning sulphur and hydrogen. These vents will fuse steel and hence reach a temperature of at least 1350°.

The zone of surface heating is a somewhat paradoxical region at the lava surface where hot fountaining and hot "bright lines"

compete with enormously rapid radiation and crusting, which latter ordinarily is greatly dominant. The fall in temperature upward through a surface crust 8 cm. thick is fully 400°; the rise in temperature from the region a half-meter below the crust to the "bright lines" amounts to from 100° to 150°, and to the fountains 250°. Heavy crust may form in thirty minutes and is a porous insulator from the heat of the melt beneath such that a man could stand on it for an instant without suffering. Thin crusts form instantly and continuously, the "bright lines" being wavy bands on the lava surface at the margin of the rending crust, the upwelling melt and gas eroding the air-filled vesicles of the crust. Thus heat-generation ensues, through completion of the reaction between rising unstable gas mixtures and through union with atmospheric oxygen. Foundering of crusts liberates much heat, carries down air, and induces fountaining.

It will be seen that the hypothetical gradient of cooling effect carried to the heavy crusts, disregarding the reheating due to surface reactions, would exhibit no bend upward to the right as in the diagram at depth 1 meter, but rather a curve to the left ending on the surface at about 400° (*C* in diagram). A completely crusted pool therefore, with gas reactions satisfied elsewhere, might reveal very low temperatures just beneath the surface in accordance with curve C. This may account for some of the anomalous records of group 1 (triangles), and others not here recorded which the writer has obtained with a thermocouple. It is hoped to explore this surface region more completely.

The zone of cooling from depth 7.5 meters to the surface crusts registered an average loss of temperature upward on May 2 of 70° per meter for the lower 3 meters. This middle region would appear to suffer a marked bend in the gradient from a relatively heated zone beneath. The viscosity should thus increase rapidly from depth 7.5 meters to depth 1 meter, a condition favorable for confinement of large gas bubbles beneath the zone of surface heating. The cooling is in the main due to surface radiation, aided doubtless by gas expansion. The surface heating appears to be localized and sudden, occurring as a result

of the accumulation of gas under an impervious crust, the release being continuous at times of rapid circulation and spasmodic during stagnant times.

The zone of bottom heat reaches a maximum not greater than that of the fountaining grottoes, and the gradient must recurve to lower temperatures in the stiff bench magma below. Continued measurement will show whether the relatively even temperature (1120°–1170°) of the lower 5 meters of the lake is that of the rising conduit lava. The writer surmises that it is hotter than the conduit lava, because the latter generally crusts over extensively and shows low incandescence. Geologic evidence from raised portions of the under-lake marginal slopes indicates that foundered crusts pile up beneath the lake, and experiment shows that they would glaze over and confine air. On reaching the bottom of the lava pool such accumulations, by gradually releasing air to react with the volcanic gas, would produce reheating. They would continuously soften and disintegrate, but during the prolonged reaction, always supplied by new foundering, the bottom would present what the measurement appears to reveal, a combination of viscosity and high temperature. The gaseous products of the reaction would accumulate in the zone of cooling and would be released explosively as central or border fountains where the accumulation became excessive. As yet it has not been possible to force a pipe down into the stiffer and lower bottom material which might show declining temperature. At the best, exploration of the deep region is difficult and somewhat dangerous, and such experiments as the immersion of May 2 must be carefully prepared, with expectation of many reverses.

CRYSTALLOGRAPHY.—*The thermodynamic reversibility of the equilibrium relations between a strained solid and its liquid.* F. E. WRIGHT and J. C. HOSTETTER, Geophysical Laboratory.

In the thermodynamical treatment of the effect of pressure on the melting temperature or on the solubility of a crystal it has been customary tacitly to assume that the process is reversible, because only under such conditions do the equilibria rela-

tions represented by the thermodynamic equations obtain. In case both the solid and the liquid are under the same pressure (hydrostatic compression) there is no difficulty in conceiving of a thermodynamic cycle which is reversible and from which the ordinary Clapeyron equations for uniform pressure can be derived. But in the case of a crystal under load the crystal phase is under a state of pressure different from that of the liquid; the pressure throughout the system is no longer uniform; in the passage of the material from one state to the other a pressure factor enters and tends to render uncertain the reversibility of the process. Nevertheless, its reversibility has been assumed either directly as self-evident, or indirectly by postulating conditions (semipermeable membranes, etc.) which are experimentally not attainable; but no direct evidence of the reversibility of the process has heretofore been offered, so far as the writers can ascertain, in support of this fundamental assumption.

The relations between a strained solid and its liquid have been discussed at various times by different authors under the headings of "non-uniform," "one-sided," "differential," or "unequal" pressure. Each of these titles is suggestive of the fact that in these discussions pressure was assumed to be unequal on the various parts of the system being investigated The equations between the various factors involved in the treatment of such a system have all been developed from the theoretical side, and none of them has ever been subjected to a thorough experimental demonstration. This lack of experimental evidence on the subject probably accounts for the diversity of effects postulated for a given pressure acting non-uniformly;—the effects so postulated vary a thousand-fold and should have been submitted to experimental test long ago.[1]

Perhaps the first investigator to study the effects of non-uniform pressure was James Thomson[2] who in 1862 made a careful distinction between stresses applied only to the solid phase of

[1] It may be mentioned here that preliminary results on the influence of non-uniform pressure on solubility indicate that the effect so produced is very small. HOSTETTER, J. C. J. Wash. Acad. Sci., **7**: 79. 1917.

[2] THOMSON, J. Phil. Mag., (4) **24**: 395. 1862; Proc. Roy. Soc., **11**: 473.

a system, and those stresses applied equally to both a solid and its liquid. That he regarded the process as completely reversible is clearly shown in the following quotation from his work:

> . . . . The following line of reasoning to show that stresses applied to a crystal will cause a resistance to the deposition of additions to it from the liquid, or, in other words, a resistance to its growth, will, I think, prove to be correct. When a crystal grows, the additions, it seems to me, must lay themselves down in a state of molecular fitting, or regular interlocking with the parts on which they apply themselves; or, in other words, they must lay themselves down so as to form one continuous crystalline structure with the parts already crystallized. It thus seems to me that, if a crystal grows when under a stress, the new crystalline matter must deposit itself in the same state of stress as the part is on which it lays itself. If, then, we consider a spiculum of ice growing in water, and if we apply any stress, a pull for instance, to it while it is thin, and then fix it in its distended state, and if then by the transference to the water beside it of cold taken from any other ice at the freezing point we cause it to grow, which it may do if there be no other crystal of ice beside it more free than it to receive accessions, then the additional matter will, I think, lay itself down in the same state of tensile stress as the original spiculum was put into by the applied pull. The contractile force of the crystal will thus be increased in proportion to the increase of its cross sectional area. If it now be allowed to contract and relax itself, it will give out, in doing so, more mechanical work than was applied to the original spiculum during distention. Hence there would be a gain of mechanical work without any corresponding expenditure; or, we could theoretically have a means of perpetually obtaining mechanical work out of nothing, unless it were the case that greater cold is required to freeze water into ice on the stressed crystal than on a crystal free from stress. Hence we must suppose that a greater degree of cold will be required to cause the stressed crystal to grow. . . . .

In 1878 Gibbs developed in detail the relations defining the conditions of equilibrium for solids in contact with fluids, having regard to all possible states of strain of the solids.[3] He introduced no direct evidence as to the reversibility of the process under consideration but from certain of his statements we may infer that he considered the process reversible. He made a distinction between the effects on equilibrium caused by strain in "isotropic" and "crystallized" bodies; this is stated specifically

[3] GIBBS, J. WILLARD. The Scientific Papers of, p. 184.

in his discussion of "surfaces of discontinuity between solids and fluids.[4]

While some of the more recent writers on the subject have not discussed the reversibility of the fundamental process, it is interesting to note that the reversibility of the process has indeed been questioned by Tammann[5] and by Pockels.[6] Nernst,[7] on the other hand, defended the reversibility of the process and considered that the thermodynamic treatment of such cases may be carried out exactly.

Johnston and Adams[8] in their treatment of the effects produced by non-uniform pressure on melting took the position that, inasmuch as the main process may be considered to be made up of an aggregate of reversible local meltings, the process itself may be considered reversible. Niggli,[9] following a line of reasoning similar to that used by Gibbs, held to the view that, although the actual process is not reversible, a comparison of thermodynamic potentials at the boundary solid-liquid for different states of strain in the solid is permissible. Still another method of avoiding the issue as to the reversibility of the process is that employed by Hassellblatt,[10] namely to consider the process an "indirect equilibrium."

EXPERIMENTAL.

In the present paper both experimental and geologic field evidence are given which prove the correctness of the assumption that the process, even for nonuniform pressure, is reversible and that on crystallization the liquid enters into the crystal state under the same state of strain as that of the crystal on which it is deposited. This statement is proved by three distinct lines of evidence and is supported by many other facts which have a

[4] Loc. cit., p. 316.
[5] TAMMANN, G. Ann. Phys., (4) **7**: 198. 1902.
[6] POCKELS, F. Neues Jahrb. f. Min., Centralblatt 1906, p. 667.
[7] NERNST, W. Theoretical Chemistry, 4th ed., p. 667.
[8] JOHNSTON, J. and ADAMS, L. H. Am. Journ. Sci., **35**: 212. 1913.
[9] NIGGLI, P. Zeit. f. anorg. Chem., **91**: 125. 1915.
[10] HASSELBLATT, M. Zeit. f. anorg. Chem., **93**: 75. 1915.

less direct bearing on the problem. The direct lines of evidence are:

1. Observations in plane polarized light of the relative states of strain of an isotropic crystal, growing under load in a supersaturated solution, and the layers deposited on it.

2. Examination under the petrographic microscope of the relative states of strain, after removal of the load, of a crystal and the layers which were deposited on it while it was under load.

3. Examination under the petrographic microscope of the state of strain of certain minerals in rocks—such as schists, gneisses, quartzites—which geologic field evidence proves were in part crystallized under load.

Less direct proof is afforded by experimental evidence on the relative rate of growth and the increased solubility of crystals under load; and also by the directive influence of lines of thrust on the direction of maximal rate of crystallization, as proved both by geologic field evidence and by experiment. These will be considered in the order named.

1. *The relative state of strain between a loaded crystal and layers freshly deposited upon it from its supersaturated solution.* To the crystallographer the process of crystallization of a substance consists essentially in the regular orientation, as a result of certain directive interatomic forces, of all molecules of the liquid which come within the range of influence of these forces. The crystal itself consists of regularly oriented series of the component atoms arranged in interpenetrating space lattices. As a result of the mutual interaction of these atoms or groups of atoms around points regularly arranged in space, the properties of the crystal are different in different directions; certain symmetry relations hold and find expression not only in the crystal form but also in the behavior of the crystal toward external forces such as mechanical forces (pressure, tension), chemical forces (rate of solution, crystal habit, etch figures), vibratory movements set up in the ether (X-rays, light, heat, and electric waves), magnetic forces, etc. The law of force between the atoms has not yet been established; it is known, however, that at relatively short distances (measured in millimicrons) the interatomic attraction

is slight, but increases rapidly as the distance decreases down to a certain limit. Beyond this limit forces of repulsion are set up and, as a result, the atoms are normally separated definite distances which can be accurately measured by X-ray analysis.

In case a crystal is placed under load the atoms are squeezed together, a state of strain exists within the crystal, and stress forces are set up which oppose the load and keep the crystal in equilibrium. The essential feature to note is that in this case there has been added to the force-function, valid at a particular point, a new term resulting from the stresses set up on loading the crystal. The loaded crystal is thermodynamically a different thing from the unloaded crystal; crystallographically the loaded crystal on growing orients the atoms or groups of atoms which come within the range of influence of its component atoms according to the force function which then obtains for the equilibrium and this is of course the unstressed crystal force function modified by the stresses set up on the application of the load. This conception holds whether the distribution of the strain be uniform or nonuniform within the crystal, but since with each different state of strain the energy relations in the crystal change, there can be real equilibrium only when the energy relations over any given area of the crystal in contact with the solution are the same as those over any other similar area. This postulates, in general, practical uniformity of distribution of load throughout the crystal. Incidentally it may be remarked that the energy contributed by the load to the crystal compared with the latent heat of the crystal is of a very small order of magnitude and that therefore we may conclude *a priori* that the effect of uniform or nonuniform pressure on the melting temperature or on the solubility of a crystal cannot be great.

If the above crystallographic conception of the problem be correct, a crystal growing under load should exhibit appreciably the same state of strain in a layer freshly deposited on the original crystal as exists in the part of the crystal which adjoins the new layer. Differences in strain between different parts of the original crystal, as a result of unequal distribution of load, should also be manifested in the freshly deposited layers. In other words

the atoms and group of atoms on deposition enter into the crystal state in practically the same condition of strain as that of the orienting crystal particles to which they become affixed. In view of the increased size of the crystal there is of course a general decrease in strain throughout the crystal but this affects the entire crystal (both new and old parts) and is so slight that it is not appreciable in the phenomena presented by the crystal when examined in polarized light. The newly deposited layers are not deposited in a state corresponding to that of the unloaded crystal (isotropic state) and there is no line of demarcation in strain between the original crystal and the freshly deposited layers.

Experiments. The method of observation employed in these experiments is essentially that first used by Brewster[11] in measurements of the relative strain in glass. Brewster discovered that a plate of glass under load is birefracting and that the optical effect is sensibly proportional to the intensity of the strain (load). The problem was studied later by Fresnel,[12] F. E. Neumann,[13] Wertheim,[14] Macé de Lepinay,[15] Kerr,[16] Pockels,[17] and recently by F. Coker,[18] and F. E. Wright.[19] As a result of Brewster's law that the birefringence, or path difference, is proportional to the strain, the determination reduces to the simple determination of the path difference between the two waves transmitted through the stressed crystal in a direction normal to the direction of the applied load, the faster wave vibrating parallel to the direction in which the load is applied, the slower normal to this direction. If white light be used as source of light the path difference gives rise to interference colors which follow approximately the Newton color scale. For qualitative observations uniformity of interference tint over the field near the edge under observation is a criterion for uniformity of strain in

[11] Philosophical Transactions 1814, 1815, 1816.
[12] Oeuvres Completes.
[13] Pogg. Ann., **54.** 1841.
[14] Comptes Rendus, **32, 33, 34.** 1854.
[15] Ann. chim. phys., **19:** 1–90. 1880.
[16] Phil. Mag., (5) **36:** 321. 1886.
[17] Ann. d. phys., **7:** 745–771. 1902; **9:** 220–223. 1902.
[18] Phil. Mag., **20:** 749. 1910.
[19] J. Wash. Acad. Sci., **4:** 595–598. 1914.

the crystal, provided of course the thickness of the layer traversed by the light waves remains constant. The path difference can be measured by a compensator of the Babinet, the graduated quartz, or the biquartz[20] type.

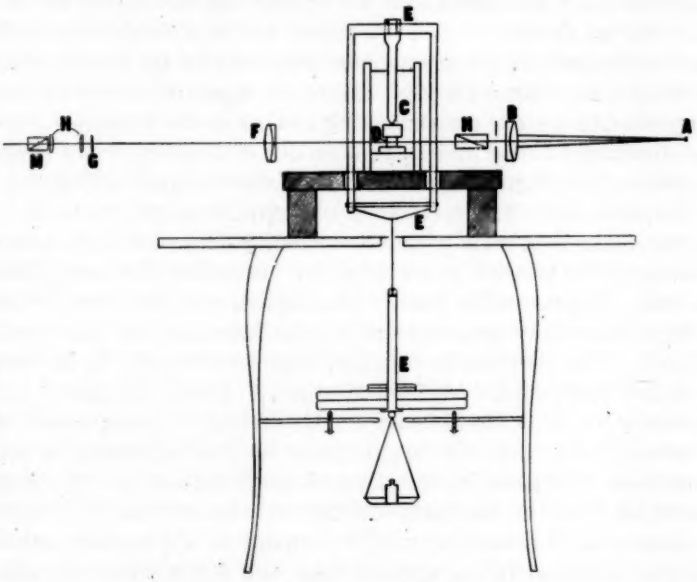

Fig. 1. Diagram showing arrangement used in the study of crystal growth under load. The crystal *D* is placed in its supersaturated solution in the tank *C* which has parallel plate glass sides. Load is applied to the crystal through a block on which the point of the loading apparatus *E* presses. Increased load is obtained by adding weights on the scale pan of *E*. A beam of parallel plane polarized light from the light source *A* is sent through the crystal into a low power microscope consisting of an objective *F*, a quartz compensator *G*, a positive eyepiece *H*, and an analyzing prism *M*.

The method actually adopted for the observation of the growing crystals is shown in Fig. 1 in which *A* is the source of light, *B* a condenser lens, *N* a polarizing prism, *C* a receptacle with plane parallel plate glass sides, *D* the loaded crystal, *E* the ap-

[20] Am. Journ. Sci., (4) **26**: 370–371. 1908; Carnegie Institution of Washington, Publication 158, 134–135. 1911.

paratus for applying the load, *F* a weakly magnifying objective lens, *G* a quartz compensator, *H* a positive eyepiece, and *M* the analyzing nicol.

Preliminary experiments were carried out on alum crystals, but for accurate measurements these crystals proved to be unsatisfactory because of the crystal habit, which is octahedral and does not allow the direct passage of the light through the crystal at the edges, since its interfacial angles are not 90°. This defect was remedied in part by grinding parallel surfaces on the crystal normal to an octahedral plane and protecting these surfaces by cover glass slips; this procedure, however, was satisfactory for quantitative measurements. The observations so far as carried proved that the octahedral layers deposited on the crystal under load are in the same state of strain as the original crystal. In order to obviate the effects of prismatic refraction the refractive index of the solution was made equal to that of the alum by the addition of glycerine, but out of this supersaturated solution crystals did not grow satisfactorily.

After unsuccessful experiments to grow large sharp unmodified cubes of sodium chloride, and also of potassium chloride, satisfactory crystals of sodium chlorate were obtained which were sharp cubes without truncations and well suited for the purpose. These crystals were not, however, entirely free from local strain but showed between crossed nicols faint interference colors of first order gray. The interference colors moreover do not change rapidly with change in load, and, to render the changes in path difference more evident, a sensitive tint plate was employed in qualitative observations.

Experiment 1. A crystal (2 by 3 by 4 mm.) was subjected to a load of about 20 kgm. per square centimeter. The load was not, however, uniformly applied, as was shown by the changes in interference colors from point to point; the unequal loading resulted chiefly from the bending of the metal disk (*D*, fig. 1) which was placed between the crystal and the rod (*C*, fig. 1); also in part from slight irregularities in the surface of the crystal. The interference colors ranged in general from first order gray to white, and were rendered more sensitive to slight changes in

path difference by the insertion of a sensitive tint plate. Under these conditions the parts of the crystal under tension appeared first order yellow, the neutral portions purple, and the parts under compression second order blue to blue green.

Deposition on each of the vertical crystal faces of the crystal under load took place at the rate of 0.12 mm. per hour, i.e., the crystal increased in thickness every half hour 0.12 mm. (0.06 mm. on a side). The interference colors in the newly deposited layers were identical with the colors in the original crystal and no line of demarcation was visible. At a point where the edge of the original crystal exhibited a neutral or sensitive violet color, there the layer in process of deposition on that point showed the same interference color, and so on for yellow and blue interference colors. The gradations from the zone of compression to that of tension in so far as they extended to the outer vertical surface under examination were conformable with the gradations in the original crystal. In short there could be no doubt that the material on deposition from the supersaturated solution entered into the crystal state in the state of strain of the crystal atoms to which it became affixed. So far as measurements could be made, the change in path difference for a load of 20 kg. per square centimeter is about 200 $\mu\mu$ per 1 cm. of material traversed. This value is not accurate but is only a rough approximation. On release of the load the crystal returned to its original condition.

After one hour's growth under these conditions the load was increased to 40 kg. per square centimeter; the path difference increased to about double the former value and the zones of compression and tension were more sharply marked, with a narrow zone of gradation between the two. As before, the freshly deposited layers entered into the crystal state in the condition of strain of the part of the crystal on which they were in contact. The load was increased to 60 kg. but this exceeded the crushing strength of the crystal, which broke into fine powder on yielding.

Other experiments with other crystals yielded similar results and need not be described in detail.

2. *Examination in polarized light of crystals which have grown under load.* In the case of a crystal which has grown under load, the original crystal on application of the load was put into a state of strain; on release of the load the crystal resumed its original state of no strain, or isotropism. In case the layers which were deposited on the strained crystal were laid down in any state of strain other than that of the original crystal, then on the release of the load a difference in the state of strain should exist between these layers and the original crystal, since the same load, or release of same, cannot arbitrarily produce different states of strain in the same material under the same conditions. On the other hand if examination shows that there is no difference in strain between the new and the old material after release of the load the conclusion is valid that the material was deposited in the state of strain of the original crystal at the time of deposition.

Examination under the petrographic microscope of crystals of alum and of sodium chlorate on which the outer layers had grown while the crystal was under load, showed no difference in state between the outer and the inner parts of the crystals. Most of the crystals were not uniformly isotropic but exhibited areas of compression and of tension (differences in interference color) and these areas passed indiscriminately and without break from the central part to the outer layers of the crystal, thus confirming the evidence gained by direct observation of crystals growing under load.

Geologic field evidence. To the student of rocks the presence, in metamorphic rocks which have been in part recrystallized, of layers of fresh crystal substance on original crystals which at the time of deposition were under heavy strain is a fact of common observation. Thus in quartzites and metamorphic sandstones the further growth, under load, of the original sand grains by the deposition of fresh material is clearly shown; similarly the growth of feldspars. On the other hand the growth of such metamorphic minerals as garnet, which are commonly isotropic when examined under the microscope but which at the time of formation were under conditions of heavy strain, proves that the

crystal state as modified by any external mechanical system of forces is the state into which freshly precipitated material enters when deposited on the crystal to which it becomes affixed.

Many more examples of a geologic kind of the growth of minerals under strain might be cited, but the above suffice to establish the fact that, whatever is the nature of the orienting polar crystal forces, when these are modified slightly by external forces, the resultant of the two systems dominates and orients groups of atoms in the act of crystallization, as they become affixed to the strained crystal, in such a way that they conform to the state of deformation of the original material.

Evidence of growth and solubility rates. In experiments on the rate of growth and the rate of solution of alum crystals which are not uniformly strained, it has been repeatedly observed that the points of greatest strain dissolve more rapidly than areas of the same crystal which are under less strain; also that on crystal growth the areas of less strain tend to grow more rapidly than areas of greater strain. This indicates that the state of strain of a crystal is a factor to be considered in problems of crystal growth. If the freshly deposited layers did not enter into the state of strain of the original crystal but in an isotropic state there should then be no difference in the rate of growth for differently strained parts of the crystal; similarly the fact that the rate of solubility is affected by mechanical strains proves that the strained crystal is in a state different from that of the unstressed crystal.

Evidence of effect of thrust on direction of crystal growth. That the direction of mechanical thrust has a direct influence on the direction and rate of growth of crystals is proved by geologic field evidence and also by laboratory experiments.[21] In the laboratory experiments cubes of wollastonite and other silicate glasses were held under load at a temperature at which crystallization took place slowly, but at which the glass was still relatively rigid and able to support a load without much flow. Longitudinal sections across the cubes crystallized under these conditions showed that the prismatic directions of the crystals

[21] WRIGHT, F. E. *Schistosity by crystallization.* Am. Journ. Sci., (6) **190.**

in the central portion of the cube were invariably normal to the direction of the applied load in the direction of least resistance, which is also the direction of flow. Further experiments along this line with polymorphic crystals of low inversion temperatures and of prismatic forms, are in progress. These prove that external directive pressure is a factor which enters into the crystal force system, and are in accord with the results cited above.

Summary. Experimental proof is offered in the foregoing pages of the reversibility of the relations between a strained solid and its liquid. The mechanism of this action has been found to be exactly that postulated in 1862 by James Thomson from a purely theoretical basis: namely, that, on crystallization, each particle (atoms and groups of atoms) enters into the crystal state in the condition of the crystal at the point to which it becomes affixed; and that if the crystal be under a state of strain the freshly deposited particle enters into the same state of strain. This fact is essential if equilibrium relations are to exist between a strained crystal and its liquid, because only under these conditions can the relations be strictly reversible, and thermodynamic reversibility is necessary if the thermodynamic equations are to be valid.

MINERALOGY.—*Ilsemannite, hydrous sulphate of molybdenum.* WALDEMAR T. SCHALLER, Geological Survey.

A secondary blue molybdenum mineral was described in 1871 and named ilsemannite; according to Dana,[1] it is cryptocrystalline and blue-black to black, becoming blue on exposure. The mineral is readily soluble in cold water to a deep blue solution. It has never been analyzed quantitatively and its composition has been assumed to be $MoO_2.4MoO_3$. Recent analysis of material from near Ouray, Utah, has shown that the amount of molybdenum in a lower state of oxidation is insignificant and that practically all of the molybdenum is present as MoO_3.

[1] DANA, E. S. System of Mineralogy, 6th ed., p. 202. 1892.

Furthermore, the mineral is a sulphate and is not an oxide nor a molybdate of molybdenum.

The occurrence of ilsemannite near Ouray, Utah, has been investigated from the geological side by Frank L. Hess of the United States Geological Survey, who is preparing a report on this subject. The present paper, which is of a preliminary nature, aims to give briefly the mineralogical features of the blue molybdenum mineral, as the complete study has been unavoidably interrupted for a time.

The ilsemannite from Ouray, Utah, is disseminated through a rock, analysis of which shows that about 10 per cent of the sample is soluble in cold water. The analytical figures are given in Table 1.

TABLE 1

ANALYSIS OF ROCK CONTAINING DISSEMINATED ILSEMANNITE, FROM NEAR OURAY, UTAH

		ANALYSIS	RATIOS	RATIOS AFTER DEDUCTING MELANTERITE	
Insoluble in water		90.50			
Soluble in water	FeO	0.99	0.014		
	MoO_3	2.37	0.017	0.017	1
	MoO_2	trace			
	SO_3	2.64	0.033	0.019	1
	H_2O (by diff.)	3.50	0.194	0.097	5
		100.00			

The water-soluble portion contains iron sulphate, and the consumption of permanganate in titrating this solution exactly equals the amount of iron (as ferrous iron) determined gravimetrically. There is present, therefore, only an undeterminable amount of molybdenum in a lower state of oxidation. Wells[2] found similarly that the deep-blue mine water from the Lucania tunnel, Idaho Springs, Colo., although containing 7.98 grams MoO_3 per liter, contained only an undeterminable trace of MoO_2. The coloring effect of this trace of MoO_2 seems to be very intense.

[2] Quoted by HORTON, F. W., in *Molybdenum: its ores and their concentration.* U. S. Bur. Mines Bull. 111, p. 15. 1916.

Tests made on ilsemannite from other localities show that iron sulphate is present in all specimens examined, and if, therefore, the figures for melanterite are deducted from the ratios given above, the remainder gives the ratio of MoO_3: SO_3: H_2O as 1:1:5. It is suggested, therefore, that the formula of ilsemannite be taken as $MoO_3.SO_3.5H_2O$ until further quantitative analysis, on pure material, shows a difference. The analysis of the deep-blue mine water from Idaho Springs, Colo., approximates closely, after deducting for other sulphates, to a ratio of 1:1 for MoO_3: SO_3, and this mine water is probably a solution of ilsemannite. A sulphate of molybdenum, $MoO_3.SO_3$, has been prepared artificially.

A specimen from Saxony showed abundant ilsemannite mixed with iron sulphate, and selected portions of the blue mineral gave a strong sulphate reaction and showed only a small amount of iron. Another specimen from Carinthia gave a strong sulphate reaction with no ferrous iron and only a trace of ferric iron. These two specimens were kindly loaned by Col. Washington A. Roebling, of Trenton, N. J. The ilsemannite from Cripple Creek, Colo., described by Lindgren and Ransome[3] gives likewise a strong sulphate reaction. It is suggested that what is called a new molybdenum mineral by Horton[4] is either a yellow sulphate of iron or yellow molybdite impregnated with a blue solution of ilsemannite, the combination of the blue and yellow producing green. Such a green coating was observed on the specimen from Cripple Creek, Colo.

The origin of ilsemannite should be studied in detail for each occurrence, but the following suggestions may be offered:

1. Oxidation of molybdenite: $MoS_2 + O_9 + 6H_2O = MoO_3.SO_3.5H_2O + H_2SO_4$.

2. Oxidation of jordisite,[5] the colloidal form of molybdenite, the powdery character of jordisite allowing of more ready oxidation and alteration.

[3] LINDGREN, W., and RANSOME, F. L. *Geology and gold deposits of the Cripple Creek district, Colorado.* U. S. Geol. Survey Prof. Paper 54, p. 124. 1906.

[4] HORTON, F. W. Op. cit., p. 15.

[5] CORNU, F. Zeitschr. Chem. Indust. Kolloide, 4: 190. 1909.

3. Decomposition of molybdates, the explanation offered for the formation of ilsemannite from wulfenite at Bleiberg, Carinthia.

4. The decomposition of a molybdenum-bearing silicate, such as molybdosodalite.[6]

The analysis of ilsemannite from Utah shows a percentage of 2.37 MoO_3 for the sample of rock taken. Other samples showed only about half as much molybdic oxide, but the average percentage of water-soluble molybdenum contained in the rock as a whole is not known.

BOTANY.—*Seedling morphology in palms and grasses.* O. F. COOK, Bureau of Plant Industry.

Morphological interpretation of the grass embryo has developed a voluminous and highly technical literature, a recent contribution being a paper by Worsdell on The Morphology of the Monocotyledonous Embryo and of that of the Grass in particular.[1]

From the standpoint of the palms, the effort to interpret the first leaf-sheath of grasses, the so-called coleoptile, as a part of the cotyledon appears artificial and unnecessary. Worsdell carried this idea to the extreme of identifying the coleoptile with the ligule of a very highly specialized cotyledonary leaf, the nursing foot, or scutellum, with the blade, and the epiblasts with auricles of the blade.

Comparison with the germination of the palms would make such assumptions unnecessary. It is possible to interpret the seedling organs of palms in simple terms of general morphology that writers on grasses leave out of account. The grass embryo has its specialized features, but there can be no advantage in undue elaboration of the differences.

THE PLANT BODY METAMEROUS

The general fact to be kept in mind is that plant bodies are metamerous, that is, made up of phylogenetically and mor-

[6] Described by ZAMBONINI, F. Mineralogia Vesuviana, p. 254. 1910.

[1] Annals of Botany, **30**: 509–534, October, 1916, with bibliography.

phologically equivalent units of structure, the phytomers, as they have been called. A typical, vegetative phytomer is represented by one of the internodes, or sections of a jointed plant stem, together with the roots that may grow from the surface of the internode and the leaf that it bears at the distal end. A terminal bud, and usually one or more lateral buds, are formed within the sheathing base of the leaf, so that a succession of phytomers can be produced.[2]

Cotyledons are leaves of the first phytomers of young plants, the internode element of this phytomer being represented by the so-called hypocotyl, or basal joint of the plant stem, from which the roots grow down. Other joints of the stem send out roots from lateral surfaces. In some palms the roots are confined to the ends of the internodes but in others they grow adventitiously from any part of the surface.

GERMINATION IN PALMS AND GRASSES

Germination commonly begins with the elongation or downward growth of the hypocotyl and the roots. In palms and grasses, the development of the hypocotyl is relatively slight, a biological deficiency that has been made good in different ways in the two groups. The grasses have small seeds which are easily buried, and germinate quickly in a few days, whereas the palms have the largest of all seeds and germination is a process of weeks or months.

The method of germination of some of the large-seeded palms is most remarkable. The function of the hypocotyl in dicotyledonous plants is performed by a petiole or elongated base of the cotyledon, which grows out of the seed and burrows into the soil, taking the plumule with it. In some cases the cotyledon elongates to the extent of several inches. In the germination of the so-called double-coconut *Lodoicea seychellarum*, the largest of all seeds, the cotyledon attains a length of several feet. After the burrowing cotyledon of a palm has grown to its full length, the tip, representing the hypocotyl, sends out roots,

[2] Cook, O. F. *Morphology and evolution of leaves.* Journ. Washington Acad. Sci., **6**: 537. 1916.

and splits open on one side for the emergence of the plumule. Thus the cotyledon itself, like all of the subsequent leaves of the palms, has a sheathing base.

After being planted by the elongated burrowing base or petiole of the cotyledon, the palm embryo encounters the same problem of pushing its way to the surface of the soil as does the grass embryo, and has solved it in a similar way, by specializing the lower joints of the plant axis. Instead of producing complete, bladed leaves, the internodes immediately above the cotyledons of palms and grasses produce only small, rudimentary leaves, in the form of narrow, cylindrical bladeless sheaths.

The germination of the maize plant shows the extent to which these specializations have been carried in grasses. Even when the seeds are buried under several inches of soil the bladeless first leaf, or coleoptile, may be carried up to the surface by the growth of a specially elongated root-bearing section of the axis. The extreme cases are found in some of the varieties of maize grown by the Hopi, Navajo, and other native Indian tribes of the dry table-lands of New Mexico and Arizona.[3]

The more or less elongated section of the stem below the coleoptile of the maize is called by some writers *hypocotyl*, by some *epicotyl*, and by still others *mesocotyl*, the name depending upon whether the organ was supposed to be a part of the cotyledon or a distinct morphological element above or below the cotyledon. Some others have looked upon the coleoptile as the cotyledon. If both the scutellum and the coleoptile are considered as parts of the cotyledon, the intervening structure has to be reckoned likewise as a part of the cotyledon. On this basis, mesocotyl would be the more appropriate term, and it may also be justified on the ground that the coleoptile has analogy, if not homology, with the cotyledons of other plants.

A distinct name, mesocotyl or some other, is needed, because this part of the axis, in producing roots along its entire length instead of only at the upper end, is unlike the other internodes and there are differences of internal structure. That the meso-

[3] COLLINS, G. N. *A drought-resisting adaptation in the seedlings of Hopi maize*. Journ. Agr. Research, **1**: 293–301. 1914.

cotyl is different, is not, however, a sufficient reason for supposing that it is not the morphological equivalent of the other internodes. To consider that an internode may be rhizophorous along its entire length is only to recognize in the seedlings of some of the grasses a condition that is common among palms, and is retained through the entire life-history. To hold that a root-bearing section of the axis above the scutellum is a part of the cotyledon, seems a much more violent assumption than to suppose that the internode of the coleoptile has retained the primitive root-bearing function. To deny that the mesocotyl represents the internode of the coleoptile is to assume that this internode has been suppressed and a new organ intercalated in its place.

EPIBLASTS AS RUDIMENTARY PHYTOMERS

Reduction or suppression of the leaf or of the axial element of the phytomer being very common forms of specialization, the epiblasts may be taken to indicate one or two rudimentary internodes above the scutellum. Thus the mesocotyl would belong to the third or fourth phytomer of the seedling, the one that produces the first leaf sheath, the coleoptile. It is much easier to believe that epiblasts represent rudiments of suppressed phytomers than that they hark back to auricles of a formerly more highly developed cotyledonary leaf. The so-called auricles of grass leaves are so distinctly a part of the ligular specialization that their separate survival as epiblasts seems highly improbable.

A tendency of different organs to become more alike has often to be recognized, but this idea of morphological convergence would hardly justify the assignment of parts of a foliage leaf to represent the scutellum, coleoptile, and epiblast. In order to consider these organs as parts of the same leaf it has to be assumed that the sheathing base, representing the most primitive element of leaf structure, has been suppressed, while the blade, ligule, and auricles have been retained.

PROPHYLLUM AND COLEOPTILE

The prophyllum of palms appears generally to be a double organ, formed by the concrescence of bladeless sheaths representing the reduced leaves of two very short basal phytomers of the inflorescence or the branch, in the few palms that produce branches. Usually only the basal sheath of the inflorescence shows the double or bicarinate condition, but in inflorescences of the small, trunkless palms that constitute the genus Sabal all of the spathes are compressed and bicarinate like the first.

Prophylla of grasses resemble those of palms except that they are not united on the side away from the main axis, but this condition also occurs in palms, having been observed in 1915 in a Peruvian species of Ceroxylon. Here the sides not only failed to meet in the middle but often the insertions were not directly opposite. In grasses as well as in palms the prophylla are always bicarinate and bilabiate, or biapiculate. Still more significant facts have been noted by Mr. G. N. Collins, that when buds or branches develop inside the prophylla their position is lateral, or opposite one of the carinae, instead of in the median position that would represent the axil if the prophyllum were a simple organ. A few cases were found where two buds developed in the same prophyllum, one on each side, a still more definite indication that two metamers are represented.

If it be admitted that the prophyllum is a double organ, indications of duplicity in the coleoptile do not require such an interpretation as Worsdell has proposed in homologizing the coleoptile with the ligule of the foliage leaf. Metaphanic anticipation of a double organ like the prophyllum in the seedling stage may be considered, or the alternative possibility that a double organ of the seedling is reproduced in the prophylla of the branches. A double coleoptile would mean that the leaves of two primitive phytomers are involved, one probably the leaf of the internode represented by the mesocotyl, the other a leaf whose internode element has been suppressed. But whether single or double, the coleoptile may be supposed to represent the entire sheath of the foliage leaf, not merely the ligule.

This is in line with the suggestion already made in relation to the epiblast. If we consider that two reduced leaves are united in the coleoptile, a similar reduction of leaves immediately above the cotyledon would not seem improbable. The epiblasts would be in the nature of hypophylls like those that occur on seedlings of the avocada, *Persea americana*, for several inches above the cotyledons. Epiblasts may be considered as rudimentary leaves without supposing that they have been in the past equal partners of the cotyledons, and without adopting the theory that the monocotyledons plants have been derived directly from dicotyledons. Too much stress appears to have been laid upon the number of the cotyledons, in view of the fact that variations are of rather frequent occurrence, and that the two series of plant families approximate rather closely when such groups as the Araceae, Artocarpaceae, and Piperaceae are considered.

As the metamerous organization of the plant body is especially noticeable in these more primitive members of the two series, there is the greater reason to take this feature into account in attempting to reach a morphological understanding of special structures and functions. The principle of metamerism yields a conception of the plant body as made up of equivalent units, instead of as an axis with leaves and other appendages attached.

ABSTRACTS

Authors of scientific papers are requested to see that abstracts, preferably prepared and signed by themselves, are forwarded promptly to the editors. Each of the scientific bureaus in Washington has a representative authorized to forward such material to this journal and abstracts of official publications should be transmitted through the representative of the bureau in which they originate. The abstracts should conform in length and general style to those appearing in this issue.

RADIATION.—*The emissivity of straight and helical filaments of tungsten.* W. W. COBLENTZ. Bureau of Standards Scientific Paper No. 300 (Bull. Bur. Stds., **14**: 115–131). 1917.

In the present investigation the radiation both from the inside and from the outside of the turn of a helically wound tungsten filament in an atmosphere of nitrogen was studied. It was found that the intensity of the radiation from within the turn of the helix is from 90 to 100 per cent greater than from a similar area on the outside of the turn. This is accounted for on the basis of multiple reflection within the helix. This reflection modifies the quality of the light so that it is redder than the light from the outside of the turn. The close agreement between the observed infra-red measurements of the radiation from within the helix and the computed values (obtained on the basis of multiple reflection and the reflectivity of tungsten) confirms the belief that the phenomenon is the result of multiple reflection. Tests made with a nicol prism, showed that the light from within the filament is highly polarized. This and the infra-red energy measurements both indicate that the quality of the radiation emitted differs from that of a black body. There is no indication that the temperature within the helix is higher than on the outside of the turn. A difference in temperature of 200° would be required to account for the observed difference in brightness. W. W. C.

CALORIMETRY.—*An aneroid calorimeter for specific and latent heats.* NATHAN S. OSBORNE. Bureau of Standards Scientific Paper No. 301 (Bull. Bur. Stds., **14**: 133–157). 1917.

The principle of the unstirred or "aneroid" type of calorimeter has been embodied in an instrument especially designed for deter-

minations of the specific heat and latent heat of several substances in general use as refrigerating media. Heat developed electrically in a coil located in the central axis of the cylindrical shell comprising the calorimeter is distributed by conduction to the calorimeter and contents whose initial and final temperature, when in thermal equilibrium, are measured by a platinum resistance thermometer. Heat from other sources is excluded by enveloping the calorimeter with a metal jacket separated from it by an air space and keeping this jacket during measurements at the same temperature as the calorimeter surface, using multiple thermocouples to indicate this equality. The calorimeter is adapted for use between $-50°$ and $+50°$C. and for pressures up to 70 atmospheres. The method of manipulation in making measurements of heat capacity is described, and the results of an extended series of observations to determine the heat capacity of the empty calorimeter are given.

N. S. O.

PHYSIOLOGICAL OPTICS.—*The relative sensibility of the average eye to light of different colors, and some practical applications to radiation problems.* W. W. COBLENTZ and W. B. EMERSON. Bureau of Standards Scientific Paper No. 303 (Bull. Bur. Stds., **14**: 167–250) 1917.

In the present investigation the methods are practically the same as used by previous experimenters. In the visual measurements, the spectral light was compared with a standard white light both by means of a flicker photometer and by means of an equality of brightness photometer. The source of white light was a standarized vacuum tungsten lamp. A cylindrical acetylene flame was used as a source of spectral light. The distribution of energy in the spectrum of the acetylene flame was determined with great care. Visibility curves were obtained on 130 persons, of which number 7 were known to be color blind. The visibility curve of the average eye is wider than previously observed. A mathematical equation of the average visibility is given and applications of these data to physical photometry are made. It is shown that the eye responds to light having an intensity less than 1×10^{-16} watt.

W. W. C.

GEOLOGY.—*Structure of the Vicksburg-Jackson area, Mississippi.* OLIVER B. HOPKINS. U. S. Geological Survey Bulletin 641–D. Pp. 93–120, with 1 plate. 1916.

The object of this report is to show which of the areas in west-central Mississippi that were examined by the Survey are considered

favorable and which unfavorable for the occurrence of oil, to discourage drilling in the unfavorable localities, and thus to aid those interested in making conclusive tests to determine the presence or absence of oil and gas.

All the rocks of the area are sedimentary in origin and are relatively young, the exposed rocks ranging in age from Claiborne (Eocene) to Recent. Of these formations the loess and the Jackson underlie by far the greater part of the area, and the Vicksburg and Catahoula formations and the terrace sand and gravel underlie smaller areas.

The general structure of the Gulf coastal plain is simple. A series of beds slopes gently southward and passes successively deeper and deeper beneath more recent deposits toward the coast. This general dip toward the coast is interrupted by local steepening or flattening and in a few places by a reversal in direction. These irregularities of dip, which are of greatest significance in the accumulation of oil and gas in valuable pools, are well illustrated in the Vicksburg-Jackson area. The geologic structure is represented on a map by contours on the Vicksburg limestone. The possibilities of oil and gas occurring in the area are discussed and the most promising areas for prospecting are pointed out. R. W. S.

TECHNOLOGY.—*The effusion method of determining gas density.* JUNIUS DAVID EDWARDS. Bureau of Standards Technologic Paper No. 94. Pp. 30. 1917.

In cooperation with a number of men employing this method in the natural gas industry a series of experiments was made using their apparatus under field conditions. It was found that results in error by more than 10 per cent were not unusual. The theory of the effusion process was studied, and the effect of differences in physical properties upon the relative rates of effusion of air and hydrogen, argon, methane, and carbon dioxide at different pressures was determined. Also observations were made on the effect of the effusion pressure, the *confining medium* and the shape and size of the orifice. It is very important that the orifice be of the proper size and shape. It has been shown that the apparent specific gravity, as determined by this method, can be varied within rather wide limits by changing the conditions. However, by the observance of certain precautions in the construction and use of the apparatus, it is possible to secure results accurate to about 2 per cent. Recommendations have been made as to the most suitable type and form of apparatus. J. D. E.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE GEOLOGICAL SOCIETY OF WASHINGTON

The 318th meeting was held at the Cosmos Club, March 28, 1917.

INFORMAL COMMUNICATIONS

C. J. HARES: *Gastroliths in the Cloverly formation.* Gastroliths were found in the summer o 1916 in the Cloverly formation in the northeast portion of the Bighorn Basin, Wyoming, at about the base of Pryor Mountains in Montana. These gastroliths occur in the shale portion of the Cloverly, between the Pryor conglomerate member at the base and the Greybull sandstone member. The gastroliths occur in such large quantities and so large individually that I was led to question the theory that they were polished in the stomachs of dinosaurs and plesiosaurs, as advocated by Williston and others. The shale, however, does carry some bones of these animals. A large representative collection was made; some of the specimens are very highly polished, and others polished scarcely at all. But if the highly polished ones are true gastroliths, then it is probable that the unpolished ones are likewise gastroliths. Some of the stones are over 6 inches long. The material consists mostly of highly siliceous rocks, jasper, chalcedony, quartzite, etc.

Discussion: C. W. GILMORE spoke of the definite association of similar stones with single skeletons of plesiosaurs.

REGULAR PROGRAM

C. J. HARES: *The southern extension of the Eagle sandstone and its relation to the Niobrara shale in Wyoming.* In the summer of 1916, while mapping the Elk Basin and Byron oil fields and an area extending from Bridger, Montana, to Greybull, Wyoming, detailed stratigraphic information was obtained, showing the correlation of the Upper Cretaceous formations of Montana with those of Wyoming. The classic Cretaceous section of Montana, as worked out by Hayden, Weed, Stanton, and Hatcher, along the Musselshell River, has been carried southward by the detailed work of Lloyd, Bowen, and Hancock to the Yellowstone River. The formations so mapped include the Colorado shale, the Eagle sandstone, Claggett shale, Judith River formation, and Bearpaw shale. The upper part of the Eagle and the Judith River are mostly of fresh water origin, the others in the main are marine.

On the other hand the more or less classic section of southern and central Wyoming, as established by King, Hayden, Darton, Stanton, Knowlton, Veatch, and others, has been carried by detailed mapping by Bowen, Barnett, Wegemann, Lupton, Hares, and others, northward to the northern boundary of Wyoming and even beyond to the Yellowstone River. The area along the Montana-Wyoming State line may be likened naturally to the closing point on an engineer's survey, and it is found that the formations of the two classic sections join up for the most part, as previous general correlations have been made, but vary in certain details.

The southern and central Wyoming section includes the following formations in the Colorado and Montana group, from the bottom up, the Thermopolis shale, Mowry shale, Frontier formation, Carlile shale, Niobrara shale, Steele shale, Mesaverde formation, and Lewis shale. In the detailed work it was found that the Thermopolis, Mowry, Frontier, and Carlile are recognizable units as far north as the Yellowstone River and possibly beyond, and that along the Montana-Wyoming State line the Niobrara, as mapped in central Wyoming by Wegemann, Barnett, Bowen, and Hares, falls about 1400 feet below the top of the Colorado group and the base of the Eagle sandstone. The Steele shale along the same line includes the upper part of the Colorado shale, the Eagle sandstone, and the lower part of the Claggett formation. The Mesaverde corresponds to the upper part, or Parkman sandstone member, of the Claggett and the Judith River. The Lewis shale has been recognized as far north as the Wind River basin and Salt Creek, Wyoming.

It has been fairly definitely established that the type Eagle sandstone includes in its lower part the massive cliff-forming sandstone at Park City and Billings, but about 100 feet below the massive sandstone is a thin sand, 10 to 40 feet thick, which contains an Eagle fauna. This lower sand is rim-forming from Park City to Elk Basin and the Shoshone River, but from there south it is represented, as is the remainder of the Eagle formation, by thin-bedded sandstones and arenaceous shales. This sand has been called the Elk Basin sandstone member of the Eagle. Further, it seemingly corresponds to the Shannon sandstone as mapped in the Casper-Salt Creek region, and it may be found still farther south. The body of shale between this horizon and the Mesaverde as a rule is light-colored and sandy, whereas the shale below the Elk Basin sandstone member of the Eagle and above the Carlile shale is darker colored, contains thin limy layers, and concretions that weather reddish-brown. The southern extension of the Eagle sandstone into Wyoming seems to represent the thinning out to a feather-edge of a recessional sand that is massive, thick, and resistant in central Montana. It has been found that the upper part of the Claggett shale grows more and more sandy as it is followed southward into Wyoming and includes about 540 feet of massive sandstones and thin-bedded shales of which at least the lower part is marine; and, further, that this ridge-forming sandstone—called the Parkman sandstone member of the Claggett—corresponds to the lower part of the Mesaverde, also called the Parkman sandstone mem-

ber of the Mesaverde, as mapped in central Wyoming, and is also present in the southern part of the Bighorn Basin. The Judith River, as traced southward, includes the lower part of the Meeteetse formation and corresponds to the upper part of the Mesaverde of central and southern Wyoming. The Bearpaw shale can be recognized as a marine shale as far south as Elk Basin, and marine sandstones are recognized as far south as the Shoshone River and Greybull. Further detailed mapping will probably establish the fact that the Bearpaw corresponds in whole or in part with the Lewis shale of the southern areas. The work also shows that the formations as a whole are thinner in the northern and central Wyoming areas. Apparently the source of sediments was chiefly from the west or southwest direction. This is borne out in part by the fact that on the west side of the Bighorn Basin no purely marine beds are present above the base of the Mesaverde.

Discussion: C. F. BOWEN spoke of the feathering of the Eagle sandstone near the Musselshell River. C. H. WEGEMANN said that about 30 miles southeast of Billings the Eagle sandstone disappears among shales. T. W. STANTON called attention to the almost perfect correlation which recent detailed study had made possible.

WILLIS T. LEE: *Relations of the Morrison and Sundance formations.* Sedimentary rocks of variable character and thickness, belonging to the Sundance formation (marine Jurassic) occur in most places along the eastern foothills in Colorado as far south as Morrison, where they are 10 to 20 feet thick. They have heretofore been included in the Morrison formation but are now known to lie unconformably below the lowest dinosaur beds. These Jurassic rocks lie unconformably on Permian red beds (Lykins). Farther to the south, beds of gypsum, now referred to the Lykins, may in fact represent the horizon of the marine Jurassic. The Morrison formation rests unconformably on the Jurassic, or on the Permian where the Jurassic is absent. In the upper part of the Morrison at the type locality of this formation a small collection of fossil plants, which F. H. Knowlton has determined to be highly developed dicotyledons of Cretaceous age, was obtained. Although the plants were found above the highest known dinosaur horizon, no question has been raised as to the propriety of including the plant horizon in the Morrison formation, nor is it probable that any geologist familiar with the section in the field will raise such a question unless he discards the accepted definition and redefines the formation. These rocks, together with the dinosaur beds a few feet lower, were once classed as Jurassic because of the supposed Jurassic affinities of the dinosaurs; later as "Jurassic or Cretaceous;" and finally as "Lower Cretaceous (?)." The plants recently found are of such character as to place the rocks containing them definitely in the Cretaceous and at a horizon considerably above the base of the system. As the Dakota sandstone, usually classed as basal Upper Cretaceous, occurs above the rocks containing the plants, it is appropriate to class those between it and the Jurassic as lower Cretaceous. The Morrison formation has been regarded as a stratigraphic unit although probably

representing a long time. However, as just stated, the Jurassic beds below the lowest dinosaur horizon were incorrectly included, and there is a possibility of further restriction of the formation. But, until it is shown that the plant horizon is not properly included, the plants must stand in favor of the Cretaceous age of the Morrison.

Discussion: C. H. WEGEMANN mentioned conglomeratic sandstone above the Morrison. T. W. STANTON said that typical Dakota forms occur in eastern Nebraska, and that four of these species are found in See's Morrison.

ALFRED H. BROOKS: *Memorial to C. Willard Hayes.* (Published in the Bulletin of the Geological Society of America, **28:** 81–123.)

The 319th meeting was held at the Cosmos Club, April 11, 1917.

INFORMAL COMMUNICATIONS

G. W. STOSE: *Corals growing along the coast of Delaware.* The finding of corals as far north as Delaware raises interesting questions as to conditions of environment, means of distribution, effects of environment on size, etc.

REGULAR PROGRAM

DEAN E. WINCHESTER: *Oil-shale in the United States.* Oil-shale is an argillaceous or shaly deposit from which petroleum may be obtained by distillation but not by treatment with solvents. It must be mined like coal and then heated before its oil is made available. In the United States there are black shales, ranging in age from Devonian to Eocene, which will yield oil when heated, but so far as yet examined the oil-shale of the Green River formation (Eocene) of Colorado, Nevada, Utah, and Wyoming is by far the richest, although shale of Carboniferous age in southwestern Montana has been found to yield as much as 24 gallons of oil per short ton, and some shales associated with coal beds in the coal fields of the eastern part of the United States yield even more. Cannel coal and cannel shale are also rich. Good oil-shale is black or brownish black in color, except on weathered surface, where it is bluish gray to nearly white. The shale is fine-grained, usually slightly calcareous. It is tough and in thin-bedded specimens remarkably flexible. When freshly broken oil-shale gives off a peculiar odor like petroleum, although the rock contains but little oil that can be extracted with solvents.

Approximately 5500 square miles in northwestern Colorado and northeastern Utah are underlain by beds of oil-shale (Green River formation) thick enough to mine and apparently rich enough to warrant the development of an industry for the manufacture of shale-oil and other products. Mining conditions in the oil-shale of Colorado and Utah are much more favorable than in Scotland, where the oil-shale industry has been best developed. Crude distillation tests indicate

that the oil-shale of the Green River formation is capable of yielding more oil than the shale mined in Scotland, although the yield of ammonia (principal byproduct) may be less than that derived from the Scotch shales. Individual beds vary from place to place in thickness and character, but the apparent persistence of the individual members of the formation is remarkable.

The beds of oil-shale were laid down in fresh water which had an enormous expanse and was so deep that wave action had little effect on the sediments. The richer beds of oil-shale contain an immense quantity of vegetable matter, while the leaner beds contain much less. Algae, mosses, ferns, pollen of higher plants, fungi, and anomalous but well marked and characteristic forms of plant life are very common in the rich shale, as shown in several hundred thin sections prepared by Dr. C. A. Davis shortly before his death. Fish remains are in some places present, insect larvae, fresh-water shells, and even bird bones have been found.

It is believed that, at least in the Green River oil-shales, the oil is indigenous to the shale, being formed from the vegetal remains in the shale partly by the slow processes of nature, partly by the violent destructive distillation in the laboratory. Dr. Davis in an unpublished note says "the mineral (not organic) part of the rich bed is physically so minute that if it were the sole original material into which the bituminous matter was injected the intrusion would have greatly distorted the beds overlying the invaded ones, but no such distortion is observable. . . . If, however, the bituminous matter is held in the partly bitumified matter seen in an incompletely decomposed state in the shale, heat might decompose the parent fossil material, and petroleum in quantities proportionate to the percentages of plant remains might be produced."

Discussion: H. M. AMI spoke of extensive tests made by the Canadian government on Nova Scotian shales. Near intrusives in these shales some naturally distilled hydrocarbons have been found. The occurrence of albertite was referred to. DAVID WHITE compared albertite and gilsonite as to occurrence in fissures, and also compared the lamination and algal growths in playa deposits with structures in oil-shales. WINCHESTER added that gilsonite veins seem to have originated from oil-shales. They are found in the beds above and below the shales.

E. T. WHERRY: *Occurrence of calcite in silicified wood.* A specimen of silicified wood obtained from Yellowstone National Park and showing calcite crystals scattered through its mass was described. The calcites contain near their centers inclusions of well-preserved wood cells, but outwardly are clear, except for a dark "phantom" line a short distance from their surfaces. The wood cell material crowded out by the growth of the later portions of the crystals is heaped up as a dark rim around them, no pressure effects being shown by the cells outside of this rim. It is inferred that after the wood had rotted to the consistency of a wet sponge the calcite started to grow from solutions

impregnating the wood. At first the growth was so rapid that the wood cells were enclosed, as is the sand in "sand-calcites," but later it went on more slowly, giving opportunity for the foreign matter to be excluded. The "phantom" line probably marks a temporary cessation of growth. The absence of silica within the calcites, as well as other relations, indicates that the deposition of silica was subsequent to crystallization of the calcite.

Discussion: D. F. HEWETT mentioned the occurrence in certain clays and residual soils of calcite grains surrounded by little quartz grains, as though the quartz had been pushed aside by the growing calcite. DAVID WHITE outlined different plausible explanations of the structures described by Wherry.

R. S. BASSLER: *The value of microscopic fossils in stratigraphy.* The speaker based his remarks upon the Early Tertiary Bryozoa of North America, a monographic study of which has just been completed for the U. S. Geological Survey. He showed with the aid of specimens and lantern slides the methods of collecting, the preparation for study, and the characters employed in the classification of these microscopic fossils. Until recent years these fossil bryozoa have been considered more as perforated stones than as well organized creatures in which the perforation and ornamentation of their surface had definite physiological purposes. The relation between the morphological and skeletal variations and their physiological purposes was discussed, and finally the stratigraphic results, particularly in intercontinental correlation, were described.

Discussion: E. O. ULRICH emphasized the fact that because these fossils are studied microscopically, *specific* differences can readily be established, and only specific characters are of definite time value.

H. E. MERWIN, *Secretary.*

THE BOTANICAL SOCIETY OF WASHINGTON

The 121st regular meeting of the Society was held in Assembly Hall of the Cosmos Club at 8 p.m., Tuesday, May 1, 1917; 39 members present. The meeting was called to order by the President. Mr. BURT A. RUDOLPH and Mr. HORACE W. TRUESDELL, Scientific Assistants in the Office of Fruit Disease Investigations, and Mr. GLENN C. HAHN, Office of Forest Pathology, were elected to membership in the Society.

The regular program was devoted to a *Symposium on the District flora.* Prof. A. S. HITCHCOCK gave an outline of the plan of the flora. The flora of Washington has been studied for nearly 100 years. In 1831 Brereton's *Prodromus of the Flora Columbiana,* was published. Ward's Flora, or *Guide to the Flora of Washington and Vicinity,* was published in 1881 and several supplements have since been issued. In 1906 a mimeograph list of the vascular plants of the District of Columbia and vicinity was prepared by P. L. Ricker, Chairman of the Botanical Seminar. The Seminar Committee on Spermatophyta con-

sisted of A. S. Hitchcock, Agnes Chase, and J. H. Painter Early in 1915 Frederick V. Coville and A. S. Hitchcock undertook to organize a study of the District flora on the cooperative basis and the plan was reported to the Society in 1915. During 1915 and the early months of 1916 keys of nearly all the families were prepared. These keys were mimeographed and distributed to contributors. Mr. Coville has since withdrawn from active leadership and the flora is now under the direction of Mr. Hitchcock and Mr. P. C. Standley. A total of twenty-five contributors are at work on the different groups. A preliminary manuscript is to be turned in by June 1 and the manuscript completed by November 1 of this year.

Mr. EDGAR T. WHERRY, at the invitation of the Society, gave a paper on *Geological areas about Washington*. Mr. Wherry not being able to be present, the paper was read by Mr. Hitchcock. The most prominent geological feature is the Fall Line, which separates the Piedmont Plateau on the northwest from the Coastal Plain on the southeast. This line was named from the fact that the rivers and smaller streams flowing southwestward toward the sea often have waterfalls or rapids at or near this line. Above this the valleys are narrow and steep-sided and the contour lines close together, while below it the valleys are broad and open and the contour lines wide-spaced. The geological formations of the Piedmont Plateau are chiefly crystalline gneisses of early periods, among which may be mentioned the Carolina gneiss, granite gneiss, diorite, biotite granite, and basic igneous rocks, including gabbro, meta-gabbro, and serpentine. The Coastal Plain is occupied by unconsolidated gravels, sands, and clays deposited during successive advances of the sea during Cretaceous, Tertiary, and Quaternary periods. Gravels also occur to some extent as cappings on the hills along the edge of the Piedmont. Bogs are frequent in the Coastal Plain and rare on the Piedmont. Lime is present in the soils of the Piedmont through concentration by means of accumulations of leaf mold, although there are no highly calcareous rocks in the vicinity. Acid soils are predominant on the Coastal Plain. The speaker called attention to the condition of the flora of the two regions which he illustrated by the distribution of the species of Liliales. Those species limited to calcareous soils found chiefly on the Piedmont Plateau are *Allium tricoccum*, *Unifolium canadense*, and *Trillium sessile*. Those limited to noncalcareous or acid soils found chiefly on the Coastal Plain are *Aletris farinosa*, *Tofieldia racemosa*, and *Stenanthium gramineum*. The other species grow throughout the region and show no marked soil preference.

Mr. GEORGE B. SUDWORTH spoke on the subject *Distribution of trees in the floral area*. Mr. Sudworth traced briefly the history of the study of the trees of the District of Columbia. Lists have been prepared at various times by Ward, Knowlton, Holm, and Steele. There are about 400 species and varieties of native and exotic trees growing within the District, many of which are in Government reservations. Of the 140 species of native trees the broad-leaved trees of the District number about 122 species and varieties and are therefore greatly in

excess of all others. No arborescent representatives of the monocotyledons are found growing naturally within the District. The oaks are the most prominent among the broad leaved trees of the District and constitute from one-half to three-fourths of the upland forest cover. They consist largely of black, red, and white oak. The most prominent conifer of this region is *Pinus virginiana*. Two naturalized trees of the District deserving special mention are the Japanese paper mulberry and the Ailanthus or Tree of Heaven. Both were introduced from China and Japan and are the most thoroughly established of the exotic trees.

Mr. FREDERICK V. COVILLE discussed *Humus as a factor in plant distribution*. Mr. Coville exhibited two samples of organic matter, the one, brown, only partially decomposed remains of the leaves and roots of laurel and oak, which make up a large proportion of the acid humus of this section; the other a black, fully-reduced, nonstructural leafmold, the reduction in this case being favored by the large amount of calcium contained in the leaves from which the mold is formed. The lime content of the sample of leafmold shown was six per cent, expressed as calcium oxide. Mr. Coville discussed the effect of these two types of organic matter on the distribution of plants.

Mr. P. L. RICKER discussed *Collecting and preparing specimens*. Mr. Ricker called attention briefly to the older methods of collecting and drying plants and suggested the advisability of using corrugated driers as well as neat portfolios, especially for field work. Where corrugated driers are used the plants can be dried without change of blotters but, in case of rainy weather, the use of artificial heat is recommended.

Following this the various papers were discussed informally by the members on the program and by Messrs. SAFFORD, BEATTIE, NORTON, WAITE, LEWTON, and SHANTZ.

H. L. SHANTZ, *Corresponding Secretary*.

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